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Coupling Structures between Crystal/Amorphous Si Waveguides for In-Plane Integration

Kazuto Itoh[1], Yuki Kuno[1], JoonHyun Kang[1], Yusuke Hayashi[1], Junichi Suzuki[1], Tomohiro Amemiya[2], Nobuhiko Nishiyama[1], and Shigehisa Arai[1,2]

[1]Department of Electrical and Electronic Engineering, Tokyo Institute of Technology,
2-12-1-S3-12 O-okayama, Meguro-ku, Tokyo 152-8550, Japan
Phone: +81-3-5734-3823 Fax: +81-3-5734-2907 E-mail: itou.k.af@m.titech.ac.jp
[2]Quantum Nanoelectronics Research Center, Tokyo Institute of technology,
2-12-1-S9-5 O-okayama, Meguro-ku, Tokyo 152-8552, Japan

Abstract

In order to realize c-Si/a-Si:H mixed photonic integrated circuits, coupling structures between two material waveguides on the same plane were investigated. We theoretically showed that around 98% of coupling efficiency is achievable within the misalignment range of 50 nm.

1. Introduction

The introduction of optical interconnection into LSI chips has been studied actively because of possibilities to realize the larger-capacity and higher-speed transmission in comparison with electrical wiring [1]. In order to realize the optical interconnection, silicon photonics is expected to be one of the key technologies due to its compatibility with CMOS fabrication process and high index contrast structures. Up to now, several components such as wire waveguides, modulators with good performance were realized by crystalline Si (c-Si) [2]. However, c-Si has fixed material properties, which caused the problem to handle high optical intensity due to optical nonlinearity [3]. On the other hand, hydrogen-terminated amorphous Si (a-Si:H) could control material properties by deposition conditions. Some groups claimed less nonlinearity than that of c-Si and other groups claimed more nonlinearity than that of c-Si due to different deposition conditions [4,5].

Therefore, integration of c-Si and a-Si:H could give new freedom of circuit functions. In this work, we propose in-plain integration methods of c-Si waveguides and a-Si:H waveguides, whose refractive index is close to that of c-Si. By numerical analysis proposed structures showed high coupling efficiencies with controllable-level misalignment tolerance.

2. Device design

In this paper, we propose two coupling structure: one is directional coupler type structure shown in Fig. 1 and the other is trident type structure shown in Fig. 2. On the premise of a device design, we assumed that 220-nm high and 450-nm wide c-Si (refractive index: 3.48) or a-Si:H (refractive index: 3.58) waveguides are buried in SiO_2 (refractive index: 1.44). Under such conditions, we designed structures using Eigen mode expansion method and finite-difference method. Here it should be noted that, following discussion is based on the assumption that the controllable alignment accuracy in the state of the art electron beam lithography and stepper is better than 50 nm, because the accuracy of the alignment is confirmed by using alignment marks [6].

Figure 3 shows coupling efficiency of a directional

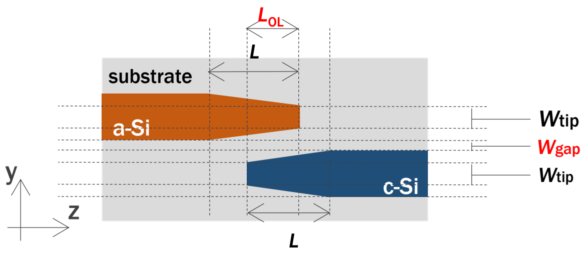

Fig. 1. Schematics of directional coupler type structure.

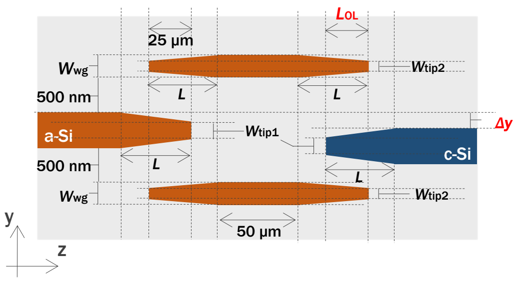

Fig. 2. Schematics of trident type structure.

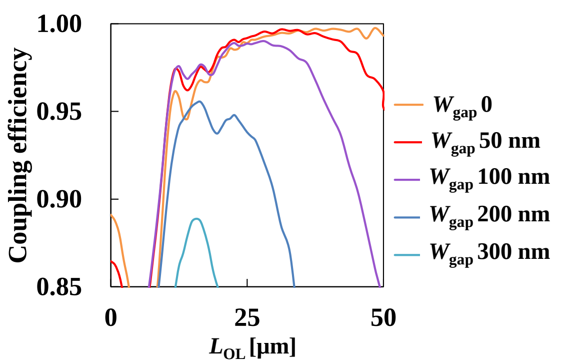

Fig. 3. Position dependence of coupling efficiency (directional coupler type structure).

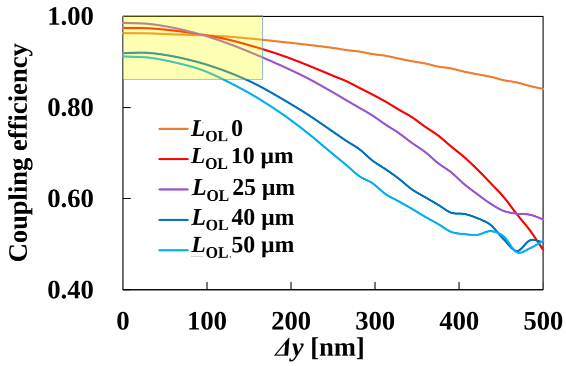

Fig. 4. Position dependence of coupling efficiency (trident type structure).

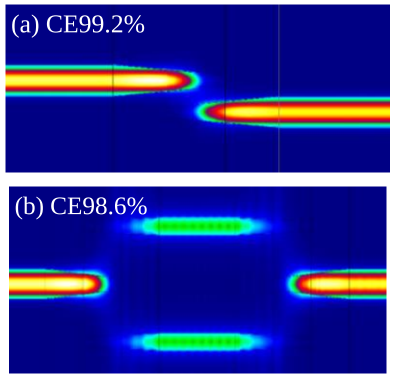

Fig. 5. Optical mode field of (a) directional coupler type structure (L_{OL} = 25 μm, W_{gap} = 50 nm) and (b) trident type structure (L_{OL} = 25 μm, Δy = 50 nm).

coupler type structure. W_{gap} indicates gap width between two waveguides and L_{OL} indicates overlapping length along z direction. As shown in Fig. 3, coupling efficiency decreases as W_{gap} widens, and it is also shown that there is a point maximizing coupling efficiency at each W_{gap}. In order to avoid decreasing of the coupling efficiency due to misalignment or manufacturing error [7], we investigated introduction of tapers into the waveguide tip. The tip width of the taper W_{tip} and the length of the taper L are set as 150 nm and 50 μm, respectively. As a result, when W_{gap} is 50 nm and L_{OL} is 25 μm, around 98% of coupling efficiency can be achieved in the area of ± 50 nm in y and z direction.

On the other hand, Fig.4 shows position dependence of coupling efficiency of the trident type structure. In this structure, the mode field size at the coupling area can be widened by controlling the position of two waveguides on either side [8]. By utilizing this property, it is possible to increase the distance between 2 cores of an a-Si:H waveguide and a c-Si waveguide.

Similar to directional coupler type structure, the tip width W_{tip1} and length L of the taper were set as 150 nm and 50 μm. Besides, the width of side waveguides W_{wg} = 250 nm, and the tip width of side waveguides W_{tip2} = 150 nm were set as constant values. From the calculation results, it was confirmed that over 90% of the coupling efficiency can be achieved in the range that overlapping length of c-Si waveguide L_{OL} = 0 - 50 μm. For example in the case of L_{OL} = 25 μm, around 98% of coupling efficiency was estimated even if ± 50 nm of misalignment was assumed.

Figs. 5(a) and 5(b) show mode fields of the two proposed structures. It is found that the trident type structure shows as high coupling efficiency as the directional coupler type structure when the trident type has a larger inter-core distance of 500 nm in comparison with 275 nm of the directional coupler type structure. Wavelength dependency of coupling efficiency is shown in Fig. 6. The directional coupler type structure shows almost constant coupling efficiency of around 99% within the wavelength range from 1530 nm to 1565 nm (C-band). On the other hand, although the trident type structure shows oscillating property to some extent, over 90% of coupling efficiency has been achieved in C-band region.

3. Conclusions

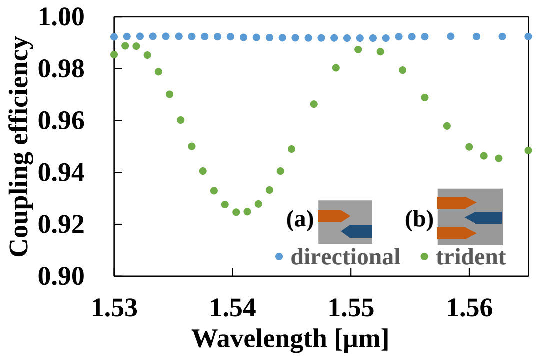

Fig. 6. Wavelength properties of (a) directional coupler type (L_{OL} = 25 μm, W_{gap} = 50 nm) and (b) trident type (L_{OL} = 25 μm, Δy = 50 nm).

As a coupling structure between c-Si/a-Si:H waveguide, we proposed the directional coupler type structure and trident type structure, and evaluated their characteristics by using Eigen mode expansion method and finite-difference method. From the calculation results, around 98% of coupling efficiency was estimated even if ± 50 nm of misalignment by using electron beam lithography.

Acknowledgment

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